Chapter 13

Dimensioning HSPA Networks: Principles, Methodology, and Applications

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13.1 Introduction

Operators are now taking another step in the development of their broadband networks by launching 3G+ and providing customers with faster mobile data services. 3G+, or 3.5G, is a natural evolution of the current (Release 99) 3G networks and promises much faster data speeds, based on HSDPA (High-Speed Downlink Packet Access) in the forward link and HSUPA (High-Speed Uplink Packet Access) in the reverse link.

In this context, capacity calculations are needed in order to dimension the system and determine whether an upgrading of the existing UMTS (Universal Mobile Telecommunications System) base stations is necessary, and, if necessary, determine if it is better to add a new carrier or share the existing carrier between 3G and 3G+. This chapter aims to respond to these questions. We present a capacity analysis of a network carrying both real-time and elastic traffic over classical 3G dedicated channels (DCHs), or on HSUPA Enhanced DCH (E-DCH) and HSDPA High-Speed Downlink Shared Channels (HS-DSCHs).

The method developed in this chapter is based on the analytical model of [1] that is adapted to the real network using HSDPA and HSUPA link-level simulations.

The methodology of capacity assessment is as follows:

- For a given offered traffic, estimate the average load of the network.
- Using the estimated load, calculate SINR (signal-to-interference-plus-noise ratio) and admission control constraints as in [1].
- Deduce quality-of-service (QoS) for DCH calls as well as the resources they consume, based on multi-Erlang analysis. As DCH traffic has guaranteed throughput, the QoS is expressed by blocking, that is, the probability that the call, upon arrival, does not have the required DCH.
- Based on the estimated load and the DCH resources, obtain the HSPA throughput values from link budget calculations.
- Using the calculated throughputs, apply processor sharing (PS) in order to obtain the HSPA QoS. The latter is expressed in terms of average throughput, or in terms of probability of having less than a target throughput.

The remainder of this chapter is organized as follows:

- In "DL R99 Model" we calculate the capacity of a Release 99 UMTS network.
- In "Capacity Analysis" we consider a UMTS carrier that has been upgraded to HSDPA and calculate its capacity.

- The same analysis is done for the uplink in "Shared R99/HSDPA Model" and "UL R99 Model."
- "R99/HSUPA Model" illustrates the analysis by numerical results.
- The "Conclusion" summarizes the chapter.

13.2 DL R99 Model

13.2.1 Radio Model

In the downlink of WCDMA, the SINR achieved for user u situated at distance r_0 from the target cell base station is given by

$$SINR_u^D(r_0) = \frac{S^D P_{u,0}/q_{u,0}^D}{I_{inter,u}^D + I_{intra,u}^D + N_0}$$

where S^D is the spreading factor; $P_{u,0}$ is the power received by user u from the target cell base station; $I_{inter,u}^D = \sum_{l\neq 0} \frac{P_{tot,l}}{q_{u,l}^D}$ is the inter-cell interference, with $P_{tot,l}$ the total power transmitted by the base station l and $q_{u,l}^D$ the path-loss between user u and base station l; and $I_{intra,u}^D = \alpha \frac{P_{tot,0} - P_{u,0}}{q_{u,0}^D}$ is the intra-cell interference originating from the common channels and from other users, with α the orthogonality factor and N_0 the thermal noise.

The total power of a typical base station in the network can be written as $\bar{\chi}^D P_{\max}$, where $\bar{\chi}^D$ is the average load and P_{max} is the maximal transmission power. Let us note that the 3G mean load is defined as the ratio between the used and the total power. This average load is not known but can be determined iteratively, as will be shown later. The inter-cell interference can be expressed in terms of the well-known F-factor [1] illustrated in Figure 13.1.

The SINR can be rewritten in the following way:

$$SINR_u^D(r_0) = \frac{S^D \times P_{u,0}}{\alpha(P_{tot} - P_{u,0}) + \bar{\chi}^D P_{\max} F_u + N_0 q_{u,0}^D}$$

where P_{tot} is the total power emitted by the target cell. Hence, after defining the β-factor of user u,

$$\beta_u = \frac{SINR_u^D}{S^D + \alpha . SINR_u^D}$$

we obtain

$$\beta_u = \frac{P_{u,0}}{\alpha . P_{tot} + \bar{\chi}^D P_{\max} F_u + N_0 q_{u,0}^D}$$

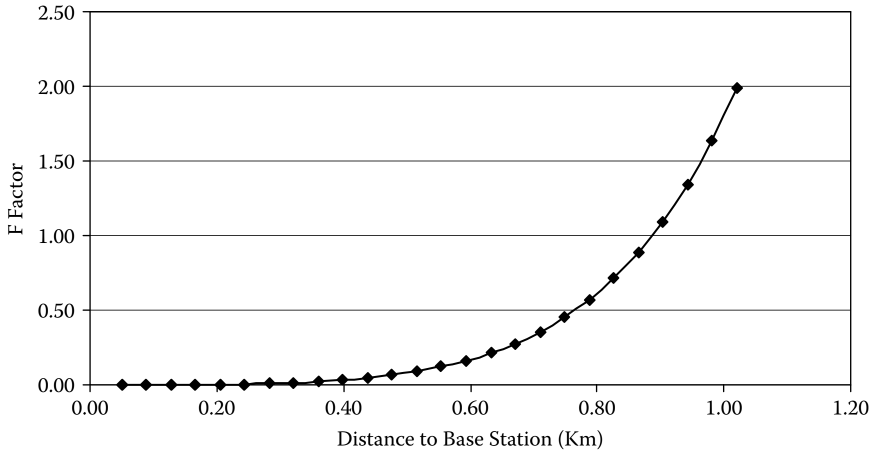

Figure 13.1 F-factor versus distance to base station.

If there are M^D UMTS users in the cell, the average total power used from the base station in the target cell is

$$P_{tot} = \frac{P_{Com} + \sum_{u=1}^{M^D} \left(\bar{\chi}^D P_{\max} F_u + N_0 q_{u,0}^D\right) \beta_u}{1 - \alpha \sum_{u=1}^{M^D} \beta_u}$$

Here we denote the power associated with the common channels with P_{Com}.

Differentiating n regions in the cell as described in Figure 13.2 and considering C classes corresponding to the nature of the DCH bearer (e.g., voice calls with 12.2 kbps, and packet-switched calls carried over channels of 64, 128, or 384 kbps), this expression of the power becomes

$$P_{tot} = \frac{P_{Com} + \sum_{i=1}^{n} \left(\bar{\chi}^D P_{\max} F_i + N_0 q_i^D\right) \left(\sum_{c=1}^{C} \beta_c M_{i,c}^D\right)}{1 - \alpha \sum_{i=1}^{n} \left(\sum_{c=1}^{C} \beta_c M_{i,c}^D\right)}$$

where $M_{i,c}^D$ is the number of class-c UMTS users in region i, for $i = 1, \ldots, n$; F_i and q_i^D are, respectively, the average F-factor and path-loss for region i.

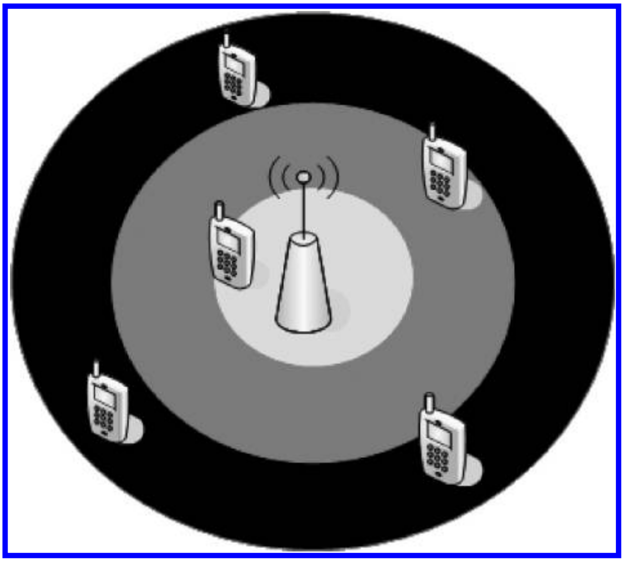

Figure 13.2 Cell decomposition.

The constraint on the maximal transmission power gives the constraint on the number of users:

$$\sum_{i=1}^{n} \left(\alpha P_{\max} + \bar{\chi}^{D} P_{\max} F_i + N_0 q_i^D\right) \left(\sum_{c=1}^{C} \beta_c M_{i,c}^D\right) \leq P_{\max} - P_{Com}$$

Let A_D be the space of states $\vec{M}^D = (M_{i,c}^D)$, $i = 1, \ldots, n$, $c = 1, \ldots, C$, where this condition is verified.

13.3 Capacity Analysis

The resolution of this system is possible using the multi-Erlang approach [4]. In fact, real-time classes will be characterized by the average call duration T_{rt}, while non-real-time classes will be characterized by the size of the file to be downloaded Z_{nrt}, which, combined with the throughput of the bearer D_{nrt} (= 12.2, 64, 128, 384), gives an average transmission time of

$$T_{nrt} = \frac{D_{nrt}}{Z_{nrt}}.$$

However, the cell is decomposed into n zones; each class is then split into n sub-classes. If the overall available capacity is $P_{\max} - P_{Com}$, a call of class-c

in zone i will consume a part of the capacity equal to $(\alpha P_{\max} + \bar{\chi}^D P_{\max} F_i + N_0 q_i^D)\beta_c$.

Let the arrival rate for the class c of traffic be λ_c and its average duration be T_c (we will have values for AMR 12.2, PS 64, PS 128, and PS 384 classes).

Once the traffic characteristics are obtained, the capacity that a call from each class will use must be determined. To do this, each class c is split into three sub-classes, leading to a new class (c,i), $i = 1, \ldots, 3$ with arrival rate $\lambda_{c,i} = \lambda_c/3$ and average duration $T_{c,i} = T_c$. Each sub-class will represent the behavior of calls in different portions of the cell (near the base station, cell center, and cell edge). If the capacity is normalized to 1, the consumed capacity of a call of class (c,i) will be equal to

$$C_i = \frac{\left(\alpha P_{\max} + \bar{\chi}^D P_{\max} F_i + N_0 q_i^D\right)\beta_c}{P_{\max} - P_{Com}}$$

The offered traffic of class (c,i) will be equal to

$$E_{c,i} = \lambda_{c,i} T_c$$

A multi-Erlang approach can thus be used, and the blocking probabilities for each service in each zone can be obtained.

13.3.1 Load Estimation

As can be shown from the above analysis, the performance measures, including the load of the cell, depend on the load of neighboring cells. However, this neighboring cell load is not an input of the model: It is an output that depends on the amount of traffic in each cell of the network. Indeed, a large offered traffic leads to a large number of simultaneous users and, consequently, a larger allocated power. As demonstrated in [2], the load of neighboring cells for a given offered traffic (in Erlang) can be approximated as follows:

$$\bar{\chi}^D = \begin{cases} \frac{\bar{E}\bar{\beta}N_0\bar{q}+P_{Com}}{P_{\max}(1-(\alpha+\bar{F})\bar{E}\bar{\beta})}, & if\ 0 \le \frac{\bar{E}\bar{\beta}N_0\bar{q}+P_{Com}}{P_{\max}(1-(\alpha+\bar{F})\bar{E}\bar{\beta})} \le 1 \\ 1 & otherwise \end{cases}$$

where $\bar{E}$ is the total offered traffic (in Erlang), $\bar{\beta}$ is the average required β-factor, $\bar{q}$ is the average path loss, and $\bar{F}$ is the average F-factor over the cell.

Once this load is known, the above-described capacity analysis can be performed and the performance measures calculated.

13.4 Shared R99/HSDPA Model

13.4.1 Radio Model

When both HSDPA and R99 calls share the same bandwidth, the power that is not used by R99 users is used for HSDPA (Figure 13.3).

The base station emits with its maximal power; so, for each UMTS user, we have

$$\beta_u = \frac{P_{u,0}}{\alpha . P_{\max} + \bar{\chi}^D P_{\max} F_u + N_0 q_{u,0}^D}$$

thus giving the power emitted by the base station to UMTS users equal to

$$P_{R99} = \sum_{i=1}^{n} \left(\alpha P_{\max} + \bar{\chi}^D P_{\max} F_i + N_0 q_i^D\right) \left(\sum_{c=1}^{C} \bar{\beta}_c M_{i,c}^D\right)$$

The admission control equation for R99 in the presence of HSDPA thus remains the same:

$$\sum_{i=1}^{n} \left(\alpha P_{\max} + \bar{\chi}^D P_{\max} F_i + N_0 q_i^D\right) \left(\sum_{c=1}^{C} \beta_c M_{i,c}^D\right) \leq P_{\max} - P_{Com}$$

Multi-Erlang analysis [4] allows obtaining, in addition to the blocking rate for R99 users, the average power $\bar{P}_{R99}$ that is used by R99 users.

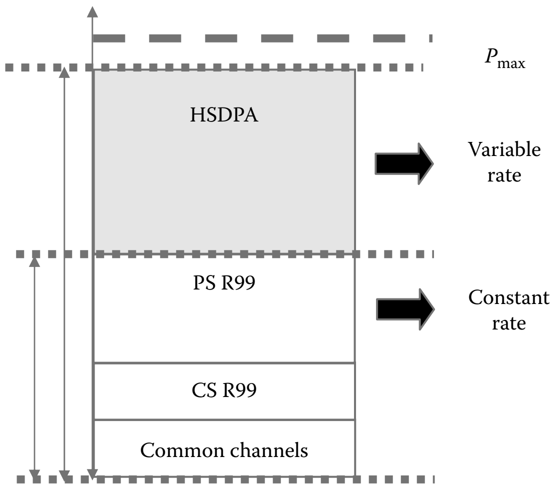

Figure 13.3 Power allocation between HSDPA and R99 users.

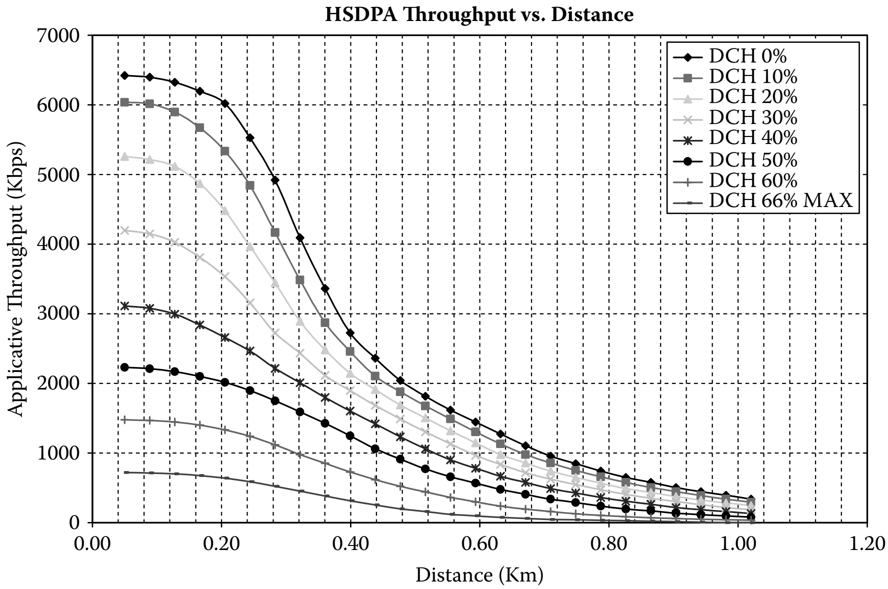

Figure 13.4 HSDPA throughput versus distance to base station, for a network load of 20% and for different values of DCH power.

Let $x = \frac{\bar{P}_{R99}}{P_{\max} - P_{Com}}$, the SINR of an HSDPA user in region j is given by

$$SINR_j^{DH}(x) = \frac{S^{DH}[(P_{\max} - P_{Com})(1 - x)]}{\bar{\chi}\, P_{\max} F_j + N_0 q_j^D + \alpha P_{Com} + \alpha x\,(P_{\max} - P_{Com})}$$

S^{DH} is the spreading factor for HSDPA.

For a given proportion of resources used by DCH traffic, link level curves [5] allow calculating the throughput of HSDPA users at each point of the cell. An example of these values is illustrated in Figure 13.4.

Let the average throughput obtained from this link budget tool in region j be equal to

$$T_j^{DH}(x, \bar{\chi}^D)$$

To assess the performance of HSDPA, we can use a processor sharing model, as in [3]. To do this, we define the load in region j by

$$\rho_j^{DH}(x, \bar{\chi}^D) = \frac{\lambda_j^{DH} Z}{T_j^{DH}(x, \bar{\chi}^D)}$$

where λ_j^{DH} is the arrival rate of HSDPA calls in region j and Z is the average file size.

The total load of the processor sharing queue is

$$\rho^{DH}(x, \bar{\chi}^D) = \sum_j \rho_j^{DH}(x, \bar{\chi}^D) = \frac{\lambda^{DH} Z}{T^{DH}(x, \bar{\chi}^D)}$$

where $T^{DH}(x, \bar{\chi}^D)$is the harmonic mean of the peak throughput over the cell surface.

If the CAC imposes that the maximal number of HSDPA users is equal to$M_{\max}^{DH}$, then the distribution of the number of users is given by

$$\Pr(M^{DH} = i \,|\, x\,, \bar{\chi}^D) = \frac{[\rho^{DH}(x, \bar{\chi}^D)]^i}{\sum_{m=0}^{M_{\max}^{DH}} [\rho^{DH}(x, \bar{\chi}^D)]^m}$$

and the blocking probability for HSDPA users is

$$B^{DH}(x, \bar{\chi}^D) = \frac{[\rho^{DH}(x, \bar{\chi}^D)]^{M_{\max}^{DH}}}{\sum_{m=0}^{M_{\max}^{DH}} [\rho^{DH}(x, \bar{\chi}^D)]^m}$$

The probability of having at least one HSDPA user in the cell is

$$\Pr(M^{DH} > 0 \,\big|\, x, \bar{\chi}^D) = \frac{\sum_{m=1}^{M_{\max}^{DH}} [\rho^{DH}(x, \bar{\chi}^D)]^m}{\sum_{m=0}^{M_{\max}^{DH}} [\rho^{DH}(x, \bar{\chi}^D)]^m}$$

If a target throughput $T_{\min}$ is fixed for HSDPA users, the probability of having, in region j, a throughput that is less than $T_{\min}$ is equal to

$$\Pr(\mathit{Throughput\ \ in}\ j < T_{\min} \,|\, x\,, \bar{\chi}^D) = \sum_{i=\left\lceil T_j^{DH}(x)/\,T_{\min}\right\rceil}^{M_{\max}^{DU}} \Pr(M^{DH} = i \,\big|\, x, \bar{\chi}^D)$$

and the probability of being under this target is given by

$$\Pr(\mathit{Throughput} < T_{\min} \,\big|\, x, \bar{\chi}^D) = \frac{1}{n} \sum_j \sum_{i=\left\lceil T_j^{DH}(x)/\,T_{\min}\right\rceil}^{M_{\max}^{DU}} \Pr(M^{DH} = i \,|\, x\,, \bar{\chi}^D)$$

The total power emitted by the base station when there is at least one HSDPA user is P_{max}. As the exact number of R99 users cannot be calculated using the multi-Erlang approach, but only the proportion of occupied resources, we can only approximate the power emitted for R99 users where there are no HSDPA calls as $P_{Com} + x(P_{\max} - P_{Com})$. The average power emitted by the cell is then

$$\bar{P} = [P_{\max} \Pr(M^{DH} > 0 \,|\, x) + [P_{Com} + x(P_{\max} - P_{Com})] \\ \times (1 - \Pr(M^{DH} > 0 \,|\, x))] \Pr(x)$$

13.4.2 Load Estimation

For a given network load $\bar{\chi}^D$, the average percentage of power used by R99 traffic can be estimated by

$$\bar{P}_{R99}(\bar{\chi}^D) = \frac{1}{P_{\max}} \min \left[\sum_{i=1}^{n} \left(\alpha P_{\max} + \bar{\chi}^D P_{\max} F_i + N_0 q_i^D\right) \times \left(\sum_{c=1}^{C} \bar{\beta}_c E_{c,i} \right), P_{\max} - P_{com} \right]$$

The minimum in this equation ensures that, for large offered traffic, the estimated power emitted by the base station does not exceed P_{max}. If we neglect blocking, the Processor Sharing queue load is equal to: $\rho^{DH}(\bar{P}_{R99}(\bar{\chi}^D), \bar{\chi}^D)$. The network load is then given by

$$\bar{\chi}^D = \min \left[\frac{P_{com}}{P_{\max}} + \bar{P}_{R99}(\bar{\chi}^D) + \left(1 - \frac{P_{com}}{P_{\max}} + \bar{P}_{R99}(\bar{\chi}^D) \right) \rho^{DH}\left(\bar{P}_{R99}(\bar{\chi}^D), \bar{\chi}^D\right), 1 \right]$$

This fixed point equation can easily be solved to obtain the network load.

13.5 UL R99 Model

13.5.1 Radio Model

In the uplink, the SNIR received from a class c mobile at the base station BS of a given cell 0 must be greater than a given constant to guarantee the reception of the signal at the BS:

$$SINR_c^U = \frac{P_c}{N_0 + I_{intra,0}^U + I_{inter,0}^U - P_c} \geq \tilde{\Delta}_c$$

for $c = 1, \ldots, C$; where $\tilde{\Delta}_c = \frac{E_c}{N_0} \times \frac{R_c}{W}$ is the required SINR for calls of class c; E_c/N_0 is the minimum allowed ratio between the bit energy and the interference plus noise density, which guarantees the target in terms of bit error probability; W/R_c is the processing gain, that is, the ratio between the chip rate and the source bit rate; N_0 is the background noise, and $I_{intra,0}$ and $I_{inter,0}$ are the total power received from other mobiles within the considered cell and all its neighbors, respectively.

The number of class-c calls in the uplink is

$$I^U_{intra,0} = \sum_{c=1}^{C} M^U_c P_c, M^U_c$$

where P_c is the constant power received by a base station for class c calls to avoid the near-far effect.

$$I^U_{inter,0} = \sum_{i=1}^{Ncell} \sum_{j} P_{i,j}$$

where $P_{i,j}$ is the power emitted by call j in cell i. We use the following analysis to calculate this interference.

The ratio of emitted power by a call in another cell j to the path loss between him and the BS 0. is

$$I^U_{inter,0} = \sum_{i=1}^{Ncell} \sum_{j} \frac{P^e_{i,j}}{q^{(0)}_{i,j}}; \quad \frac{P^e_{i,j}}{q^{(0)}_{i,j}}$$

Knowing that the transmission is power controlled in the uplink, in order to avoid the near-far effect, all calls of class c are received at their own base station with the same power P_c. On average, the inter-cell interference can then be approximated by

$$I^U_{inter,0} = E\left[\sum_{c=1}^{C} M^U_c P_c\right] \times E\left[\sum_{i=1}^{Ncell} \frac{q^{(i)}_i}{q^{(0)}_i}\right]$$

where M^U_c is the number of calls of class c in a typical cell of the system, and $q^{(j)}_i$ is the path loss between a typical position in cell i and the base station of cell j.

Let $f = E[\sum_{i=1}^{Ncell} \frac{q^{(i)}_i}{q^{(0)}_i}]$ be the interference factor in the uplink; it is obtained by integrating over the interfering cells.

$\bar{P} = E[\sum_{c=1}^{C} M_c^U P_c]$ is the average received power by a base station in the system; we will show next how to calculate it.

Considering the minimal power that can achieve the target SIR, we obtain

$$\tilde{\Delta}_c = \frac{P_c}{N_0 + \sum_{m=1}^{C} M_m^U P_m + \bar{P} \cdot f - P_c}$$

Defining $\Delta_c = \frac{\tilde{\Delta}_c}{1+\tilde{\Delta}_c}$, we can obtain

$$P_c = \Delta_c \left(N_0 + \bar{P} \cdot f + \sum_{m=1}^{C} M_m^U P_m \right)$$

which leads to

$$\sum_{m=1}^{C} M_m^U P_m = \frac{(N_0 + \bar{P} \cdot f) \sum_{m=1}^{C} M_m^U \Delta_m}{1 - \sum_{m=1}^{C} M_m^U \Delta_m}$$

and

$$P_c = \frac{(N_0 + \bar{P} \cdot f)\Delta_c}{1 - \sum_{m=1}^{C} M_m^U \Delta_m}$$

At admission control, a constraint on the load of the cell must be respected. This is expressed as a limitation on the noise rise at the reception, defined by: $\chi^U = \frac{I_{tot}+N_0}{N_0}$, where I_{tot} is the overall power received by the base station. This leads to

$$\eta^U = \frac{\sum_{m=1}^{C} M_m^U P_m + \bar{P} \cdot f + N_0}{N_0} = \frac{N_0 + \bar{P} \cdot f}{N_0 \left(1 - \sum_{m=1}^{C} M_m^U \Delta_m \right)}$$

A condition on the maximal value of this noise rise is to be imposed:

$$\eta^U < \eta_{\max}^U$$

leading to the condition:

$$\sum_{c=1}^{C} M_c^U \Delta_c < 1 - \frac{N_0 + \bar{P} \cdot f}{N_0 \eta_{\max}^U}$$

This equation describes the number of circuits required by calls. If we normalize the capacity to 1, each call of class c requires a number of circuits equal to $\frac{\Delta_c}{1-\frac{N_0+\bar{P}\cdot f}{N_0\eta_{\max}^U}}$. The capacity of the system can then be analyzed using multi-Erlang as described for the downlink.

13.5.2 Load Estimation

In a homogeneous network, we can say that the powers received by base stations from their own users are, on average, equal:

$$\bar{P} = \sum_{m=1}^{C} M_m^U P_m$$

leading to

$$\bar{P} = E\left[\frac{(N_0 + \bar{P} \cdot f) \sum\limits_{m=1}^{C} M_m^U \Delta_m}{1 - \sum\limits_{m=1}^{C} M_m^U \Delta_m}\right]$$

A good approximation of $\bar{P}$ would thus be as follows:

$$\bar{P} = \frac{N_0 \bar{\Delta}(\bar{P})}{1 - (1 + f)\bar{\Delta}(\bar{P})}$$

where $\bar{\Delta}(\bar{P})$ is the approximation of $\sum\limits_{m=1}^{C} M_m^U \Delta_m$ given the offered traffic and $\bar{P}$:

$$\bar{\Delta}(\bar{P}) = \min\left[\sum_{c=1}^{C} E_c \Delta_m, 1 - \frac{N_0 + \bar{P} \cdot f}{N_0 \eta_{\max}^U}\right]$$

A simple fixed-point solution of this equation is again possible.

13.6 R99/HSUPA Model

13.6.1 Radio Model

HSUPA aims to offer high data rates on the uplink (up to 5.76 Mbps) using key techniques implemented in HSDPA, such as fast scheduling, link adaptation, and Hybrid ARQ (HARQ). Unlike HSDPA, HSUPA does not use a shared channel for delivering the data calls. By structure, it is considered more of an add-on to the UMTS R99 standard rather than a replacement. The study of HSUPA performance will, consequently, be based on the study for the UMTS R99 uplink model.

For the admission control, the condition concerning the maximum load value won't change. This condition will then be used to allocate the available resources to the pool of the HSUPA users, knowing that there is a larger number of possible throughputs. The resulting interference configuration is described in Figure 13.5.

For R99 users, a maximal noise rise is specified taking into account only in-cell DCH users:

$$\eta_{R99}^{U} = \frac{I_{tot} - I_{HSUPA} + N_0}{N_0} \leq \eta_{R99}^{\max}$$

where I_{HSUPA} is the power received from HSUPA users.

For HSUPA users, the admission control condition is on the total noise rise:

$$\eta_{tot}^{U} = \frac{I_{tot} + N_0}{N_0} \leq RoT^{\max}$$

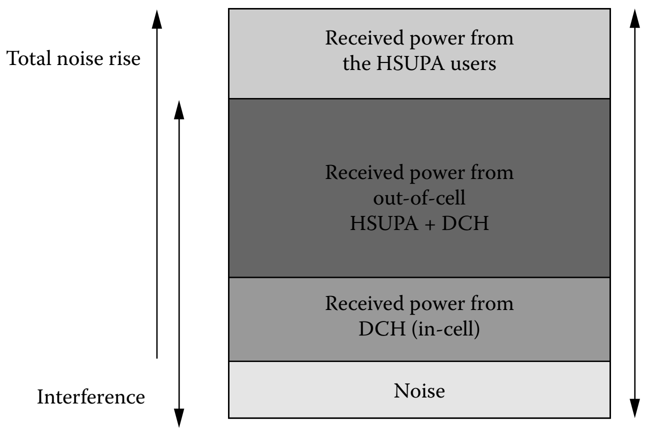

Figure 13.5 Interference budget for the uplink.

The equality holds except for coverage-limited cases where cell edge users are not able to use the overall capacity, even when they transmit with their maximal power. In this work, we limit ourselves to the RoT-limited cells, which is the case in most dense urban and urban areas.

Knowing that in the presence of HSUPA users in the cell, the maximal noise rise is attained, the SINR received at the base station for a R99 class-c user is

$$\tilde{\Delta}_c = \frac{P_c}{N_0 + I_{tot} - P_c} = \frac{P_c}{N_0\, RoT^{\max} - P_c}$$

Defining, as before, $\Delta_c = \frac{\tilde{\Delta}_c}{1+\tilde{\Delta}_c}$, we can obtain

$$P_c = N_0 RoT^{\max} \Delta_c$$

Following the above-mentioned R99 noise rise constraint, the admission control equation for R99 users becomes

$$\eta^U_{R99} = \frac{\sum\limits_{c=1}^{C} M^U_c P_c + \bar{P}f + N_0}{N_0} = RoT^{\max} \sum_{c=1}^{C} M^U_c \Delta_c + \frac{\bar{P}f + N_0}{N_0} \leq \eta^{\max}_{R99}$$

or

$$\sum_{c=1}^{C} M^U_c \Delta_c \leq \frac{\left(\eta^{\max}_{R99} - 1\right) N_0 - \bar{P} \cdot f}{N_0 RoT^U_{\max}}$$

This, again, can be resolved using multi-Erlang analysis. Such analysis gives, in addition to the blocking rate, the average resource utilization, that is, $E[\sum\limits_{c=1}^{C} M^U_c \Delta_c]$. The average noise rise due to R99 users is then calculated by

$$x = \frac{E\left[\sum\limits_{c=1}^{C} M^U_c P_c\right] + \bar{P}f + N_0}{N_0} = RoT^{\max} E\left[\sum_{c=1}^{C} M^U_c \Delta_c\right] + \frac{\bar{P}f + N_0}{N_0}$$

As for HSUPA users, their throughput will depend on three factors:

1. The power used by R99 users, expressed in a noise rise value$x$
2. The number of HSUPA users in the cell: M^U_H
3. The load in adjacent cells $\bar{\chi}^U$, crucial to determine the inter-cell interference

HSUPA link-level curves allow us to calculate the per-user throughput knowing these two values. An example of these throughputs is given in Figure 13.6 for one and three HSUPA users and a full HSUPA network.

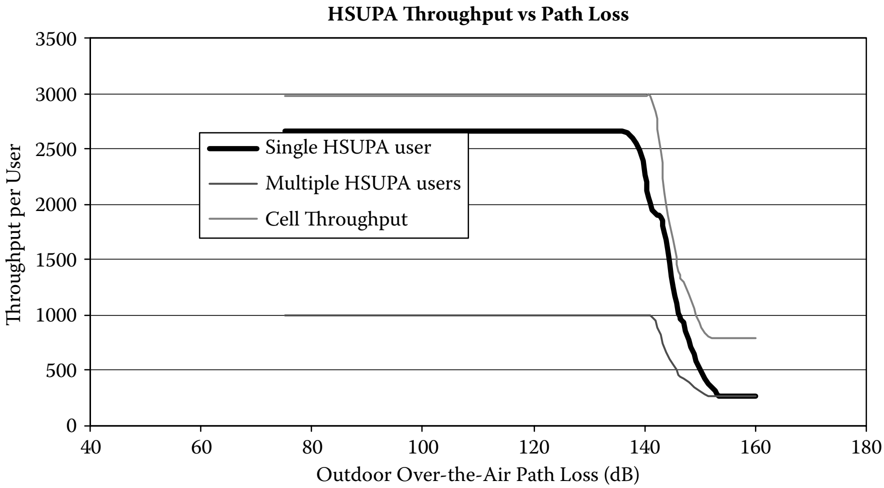

Figure 13.6 HSUPA throughput.

Let $T^{DH}(x, M_H^U, \bar{\chi}^U)$ be the overall cell throughput when the noise rise from R99 users is equal to x, the neighboring cell load is equal to $\bar{\chi}^U$ and the number of HSUPA users is equal to M_H^U. The performance of HSUPA users can then be obtained using a generalized processor sharing queue:

$$\Pr[M_H^U \,|\, x\,,\, \bar{\chi}^U] = \Pr[0\,|\,x] \frac{(\lambda_H^U Z)^{M_H^U}}{\prod_{m=1}^{M_H^U} T^{DH}(x, m, \bar{\chi}^U)}$$

with λ_H^U the arrival rate of HSUPA calls and Z the average file size. The normalizing constant is a calculated function of the maximal allowed number of simultaneous HSUPAs in the cell $M_{\max}^U$:

$$\Pr[0\,|\,x\,,\, \bar{\chi}^U] = \left[1 + \sum_{M_H^U=1}^{M_{\max}^U} \frac{\left(\lambda_H^U Z\right)^{M_H^U}}{\prod_{m=1}^{M_H^U} T^{DH}(x, m, \bar{\chi}^U)} \right]^{-1}$$

The HSUPA blocking rate is thus equal to $\Pr[M_{\max}^U \,|\, x, \bar{\chi}^U]$, and the probability of being below a given target is

$$\Pr\left(Throughput < T_{\min} \,\middle|\, x, \bar{\chi}^U \right) = \sum_{i=M_{\max}(x,T_{\min})}^{M_{\max}^U} \Pr\left(M_H^U = i \,|\, x\,,\, \bar{\chi}^U \right)$$

where $M_{\max}(x, \bar{\chi}^U, T_{\min})$ is the minimal number of HSUPA users, so that

$$T^{DH}\left(x, M_{\max}(x, T_{\min}), \bar{\chi}^U\right) < T_{\min}$$

13.6.2 Load Estimation

For a given offered traffic, two unknowns are to be determined: (1) the average power received by a base station from its own (R99+HSUPA) users $\bar{P}$, and (2) the load of neighboring cells $\bar{\chi}^U$ necessary for SINR calculations. The load of a cell is defined as the ratio of the measured noise rise to the maximal Rise over Thermal (RoT). These two values are thus correlated. In fact, we can approximate the total noise rise of the cell by

$$\bar{\eta}^U_{tot} = E\left[\frac{I_{tot} + N_0}{N_0}\right] = \frac{\bar{P} + \bar{P}f + N_0}{N_0} = \bar{\chi}^U RoT^{\max}$$

leading to

$$\bar{P}(\bar{\chi}^U) = \frac{N_0(\bar{\chi}^U RoT^{\max} - 1)}{(1 + f)}$$

More in depth, the load of the network is related to the offered traffic. Let us first approximate the noise rise due to R99 users:

$$\bar{x}(\bar{\chi}^U) = RoT^{\max}\bar{\Delta}(\bar{\chi}^U) + \frac{\bar{P}(\bar{\chi}^U)f + N_0}{N_0}$$

where

$$\bar{\Delta}(\bar{\chi}^U) = \min\left[\sum_{c=1}^{C} E_c\Delta_m, \frac{\left(\eta^{\max}_{R99} - 1\right)N_0 - \bar{P}(\bar{\chi}^U)\cdot f}{N_0 RoT^U_{\max}}\right]$$

As for HSUPA users, they will take, if present, all the resources that are not used by R99 ones. The probability that there is at least one HSUPA user in the cell is equal to the load of the processor sharing queue. This load is given by

$$\rho^U_H(\bar{\chi}^U) = 1 - \Pr[0 \left| \bar{x}(\bar{\chi}^U), \bar{\chi}^U\right.] = 1 - \left[1 + \sum_{M^U_H=1}^{M^U_{\max}} \frac{(\lambda^U_H Z)^{M^U_H}}{\prod_{m=1}^{M^U_H} T^{DH}(\bar{x}(\bar{\chi}^U), m, \bar{\chi}^U)}\right]^{-1}$$

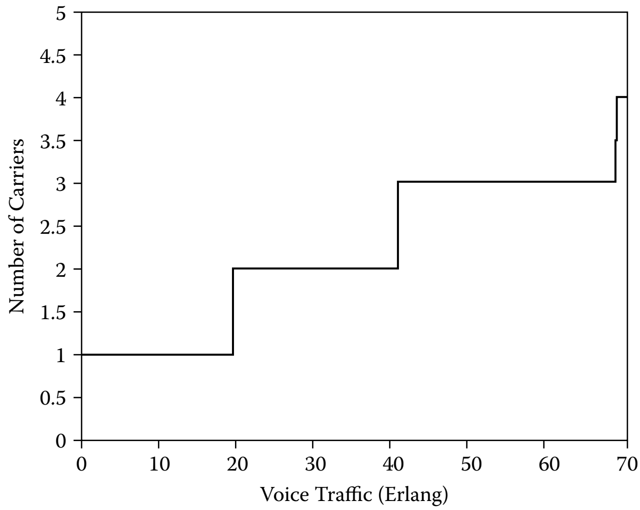

Figure 13.7 Number of carriers necessary to carry the offered voice traffic.

The average load of a cell in the network can thus be approximated by

$$\bar{\chi}^U = \frac{\bar{x}(\bar{\chi}^U)}{RoT_{\max}} + \left(1 - \frac{\bar{x}(\bar{\chi}^U)}{RoT_{\max}}\right)\rho_H^U(\bar{\chi}^U)$$

This is, again, a fixed-point equation that should be solved before evaluating the performance of the target cell.

13.7 Example of Results

Figure 13.7 shows the number of dedicated carriers necessary to carry a given offered voice traffic in a pure R99 network. In the case of a shared DCH/HSPA carrier, Figure 13.8 shows the maximal HSPA offered traffic that can be supported by one carrier.

13.8 Conclusion

In this chapter we studied the capacity of 3G/3G+ networks. We developed radio models for both downlink and uplink, and used them to derive the Erlang-like capacity of the network. We studied the cases of carriers dedicated for HSPA, as well as shared carriers where HSPA users coexist with legacy UMTS ones. These capacity models allow us to know, for a

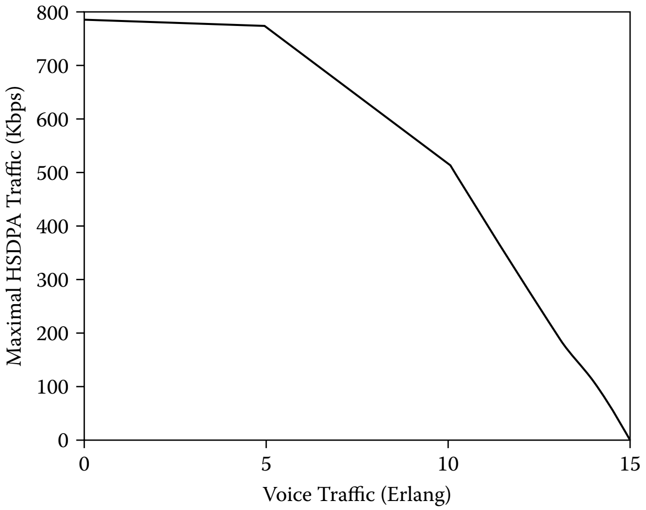

Figure 13.8 Maximal HSDPA traffic versus the voice traffic for one carrier.

given traffic pattern, the best network configuration—whether to upgrade the network by adding HSPA or add a new carrier to guarantee QoS for users.

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